Analysis of Passive Vibration Measurement and Data Interrogation Issues in Health Monitoring of a HMMWV Using a Dynamic Simulation Model

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Motivation

HMMWV comes in over a dozen variants:

- Some heavier than others;
- Variation in loading;
  - Durability of suspension,
  - Frame and cross members.

- A method is desirable through which passive vibration response is used to detect faults.

Issues

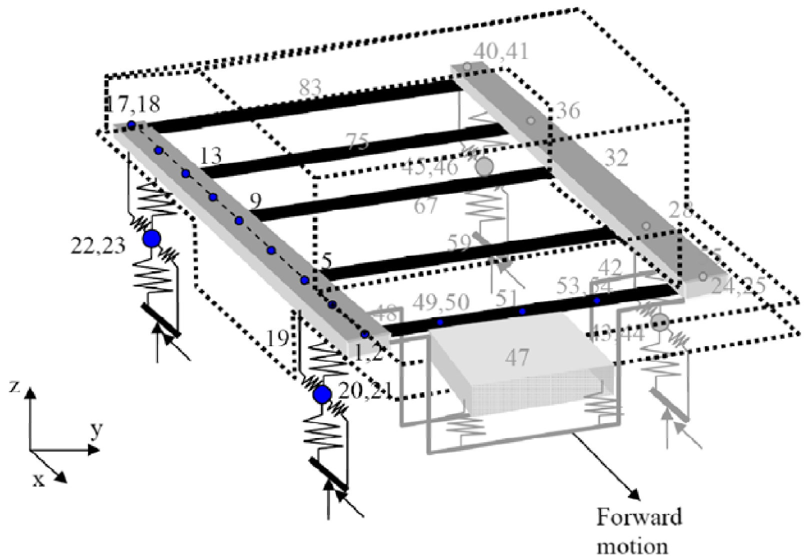
Issues with using vibration for fault detection:

- Which frequency range?
- Sensors, how many and where to place?
- Damage variety (suspension, frame, etc.).
- Non-stationary excitation due to terrain:
  - L/R wheels in phase,
  - L/R wheels out of phase,
  - Must identify operating regime first.
- Variability from vehicle-to-vehicle.

Approach

87 degree of freedom dynamic model:

$$[\mathrm{M}]\{\ddot{x}\}+[\mathrm{C}]\{\dot{x}\}+[\mathrm{K}]\{x\}=\{f\}$$



- x and z forcing functions;
- Free response analysis;

$$[\mathrm{M}]^{-1}[\mathrm{K}]\{X\}=\lambda\{X\}$$

- Force response analysis;

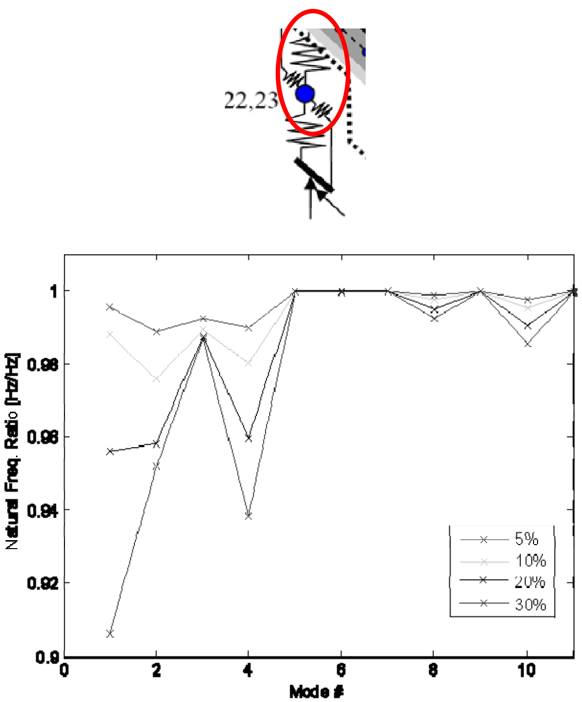
$$\frac{d}{dt}\begin{Bmatrix}\{x\}\\\{\dot{x}\}\end{Bmatrix}=\begin{bmatrix}[0] & [I]\\ -[\mathrm{M}]^{-1}[\mathrm{K}] & -[\mathrm{M}]^{-1}[\mathrm{C}]\end{bmatrix}\begin{Bmatrix}\{x\}\\\{\dot{x}\}\end{Bmatrix}+\begin{bmatrix}[0]\\ [\mathrm{M}]^{-1}\end{bmatrix}\{f\}$$

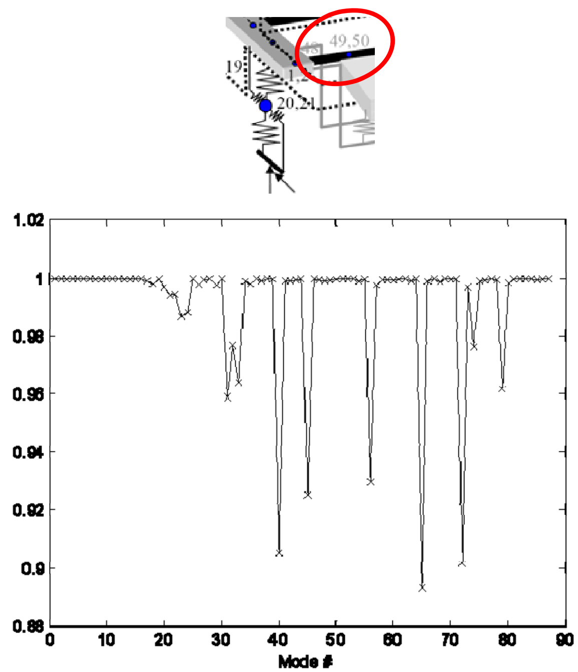
$$=[\mathrm{A}]\begin{Bmatrix}\{x\}\\\{\dot{x}\}\end{Bmatrix}+[\mathrm{B}]\{u\}$$

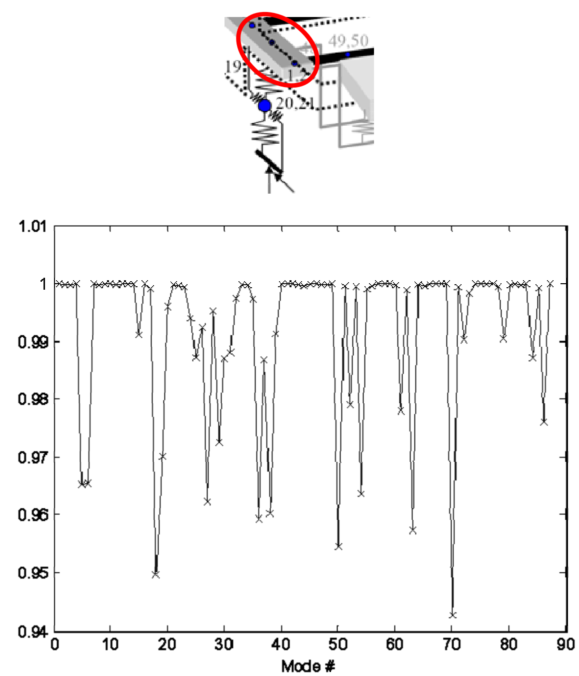
Results (Free Response)

Suspension, cross member, and frame damage:

- Low, high, and broad frequency changes,
- 40-50% damage results in 10% variation.



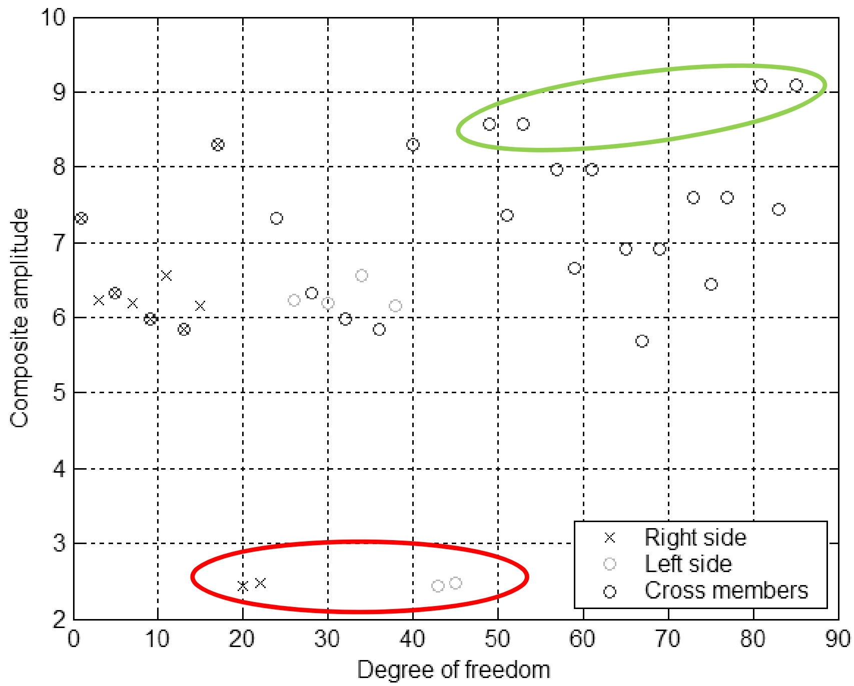


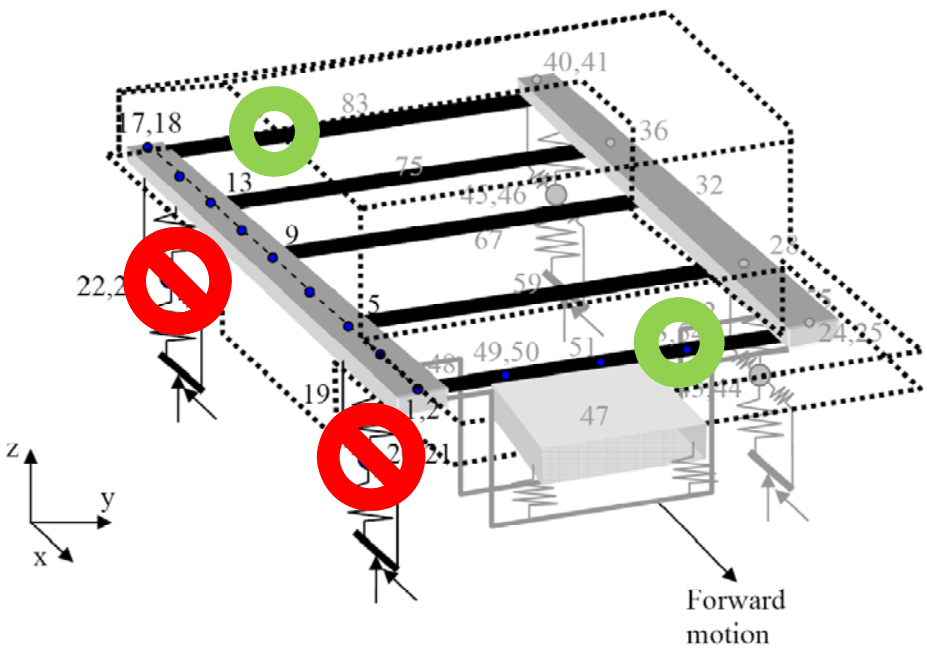


Results (Free Response)

Modal deflection shapes show that:

- Sensors on F/R cross members are optimal,
- Sensors on wheel are suboptimal (filtering).

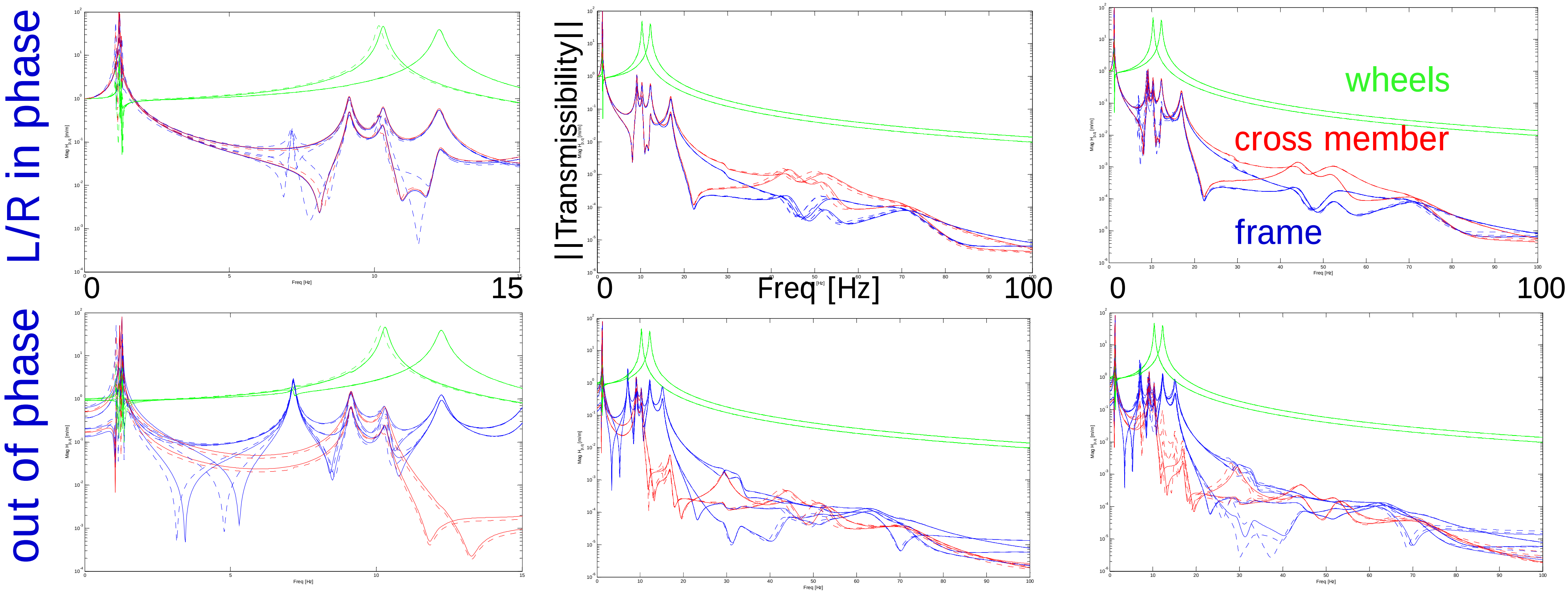




Results (Force response)

Faults in suspension, frame, cross members are:

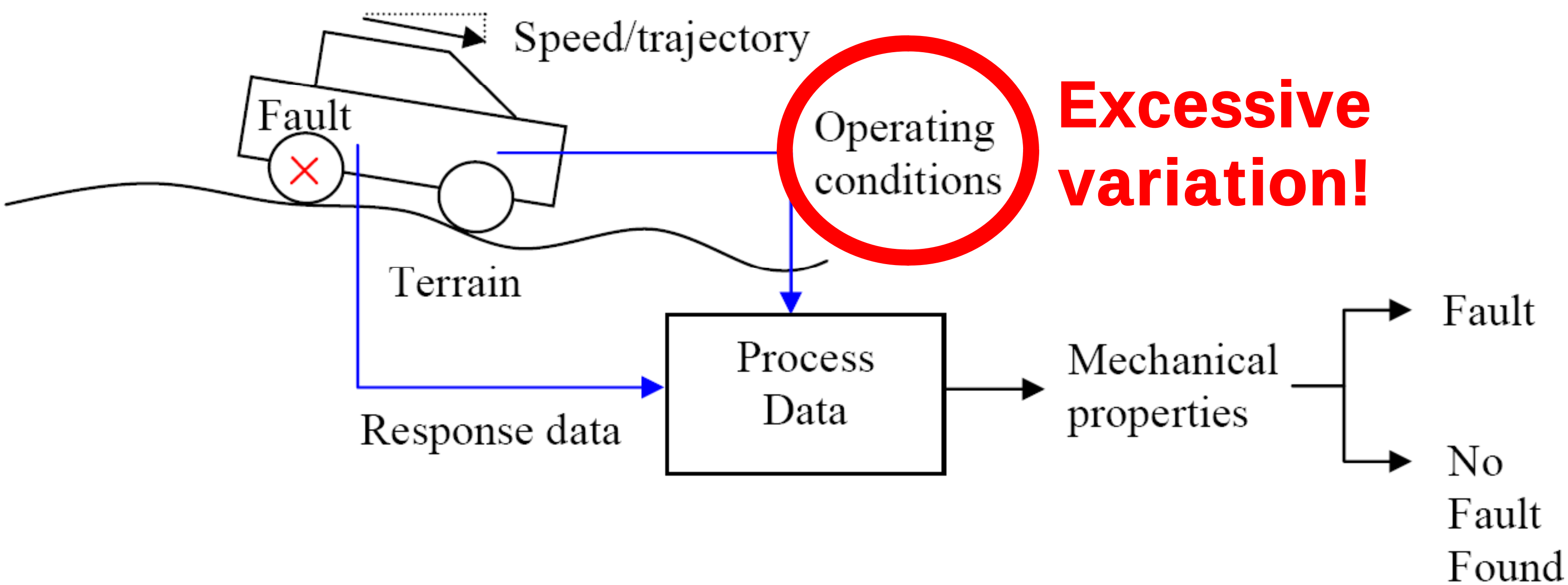
- detected in different frequency ranges;
- best detected for certain terrains (modes).



Technical Barrier

HMMWV forced response varies significantly:

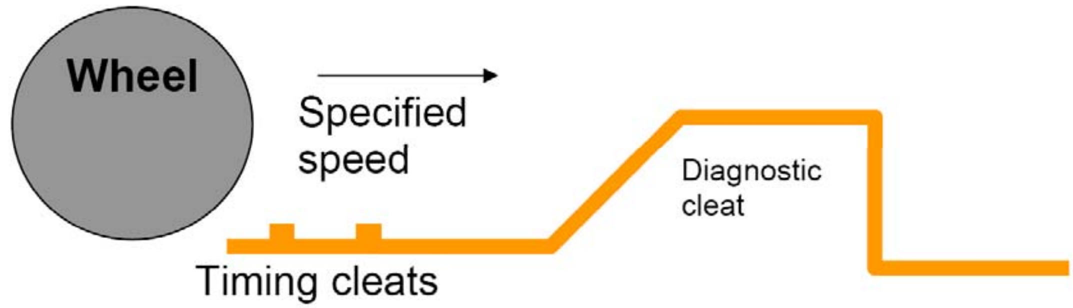
- Without regime recognition, fault detection is difficult using conventional methods.



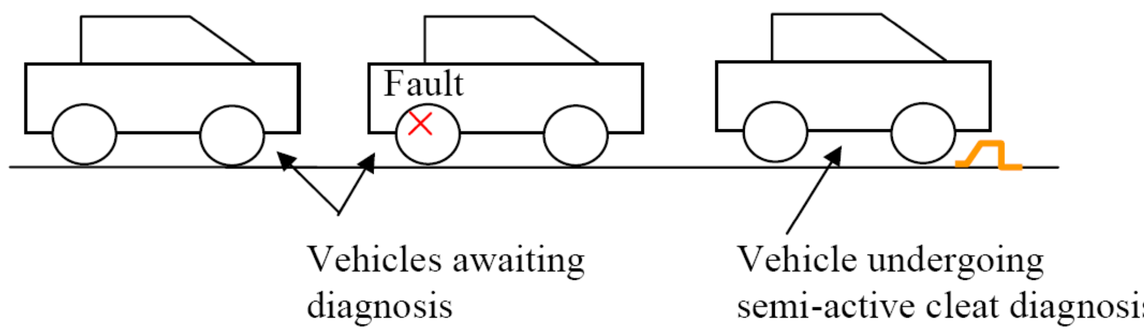
Proposed Approach

Method to control vibration input for diagnosis:

- Timing, and
- diagnostic cleats.



- "Weigh station" approach will target certain faults.



Experimental Setup

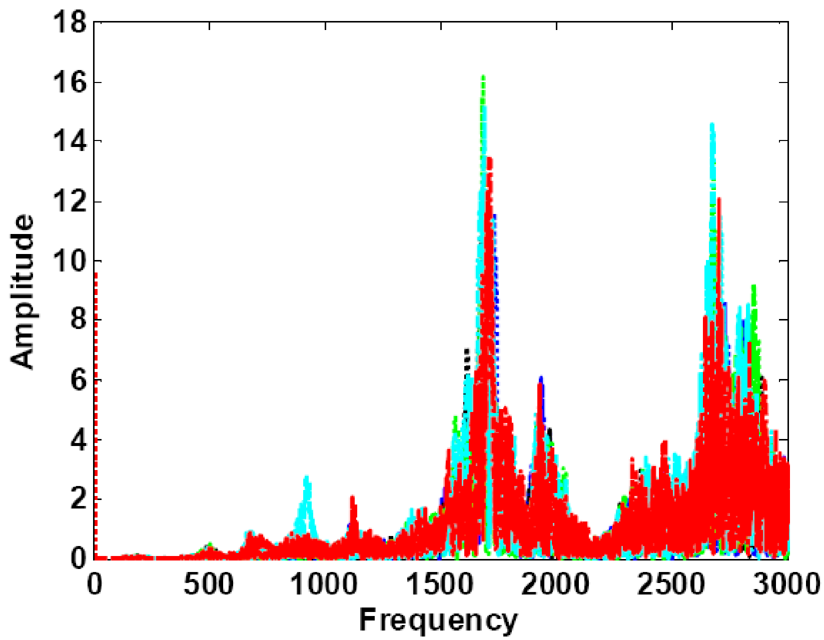
Pickup truck with 2 vertical accelerometers:

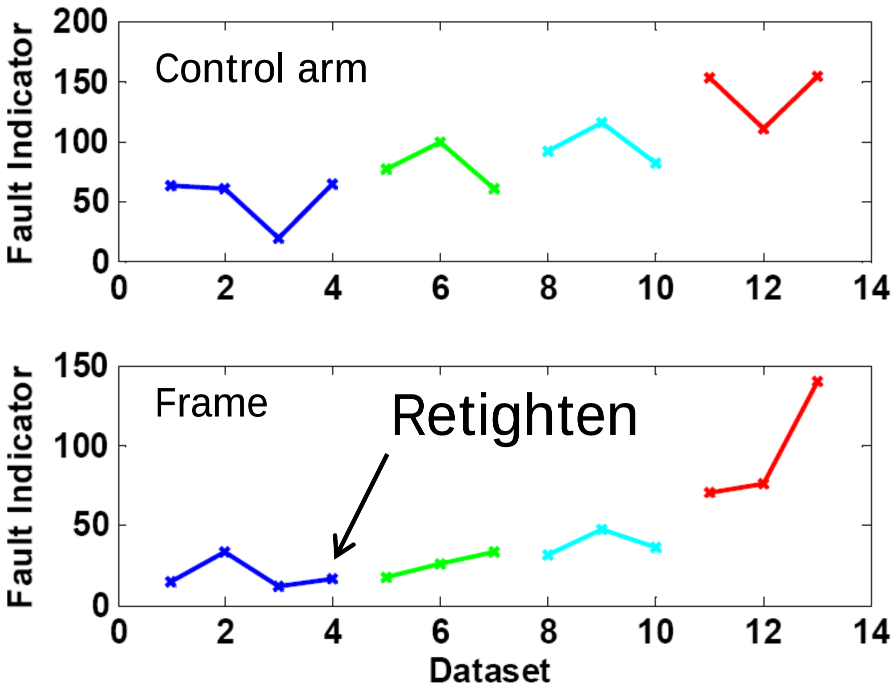
- F/R control arm and F/R frame.

Experimental Results

Sway bar link loosened to 400, 200, 0 lb-in:

- Low freq insensitive to fault;
- Both sensors sensitive from 2.6-3.9 kHz.





Conclusions

Fault detection using vibration data is feasible:

- Free response (modal) changes depend on frequency range;
- Forced response changes depend on regime;
- To control variability in fault indicators, diagnostic cleat approach is proposed;
- Experiments indicate fault in stabilizer bar link can be detected amidst variability in data.